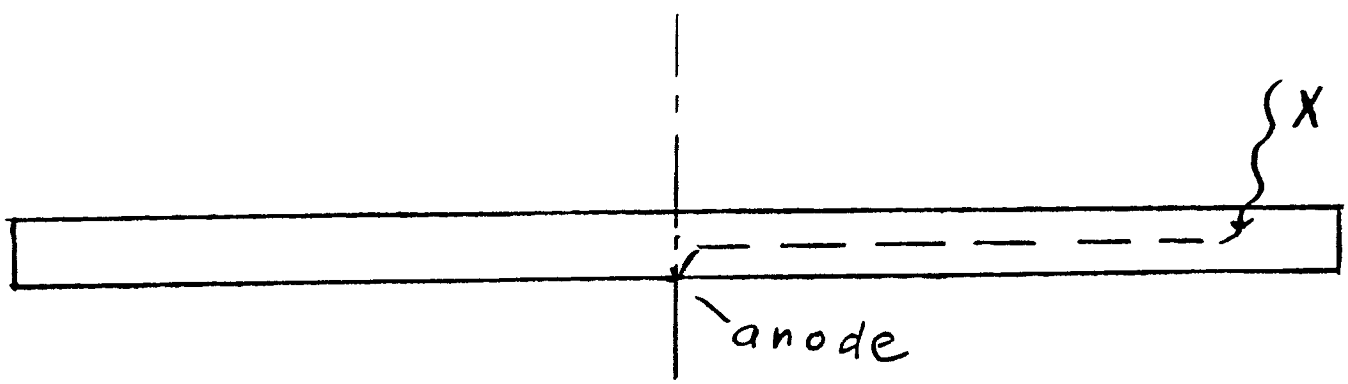
Washington

October 28–29,2000

Silicon Drift Detectors



and

Active Pixel Sensors on High Resistivity Silicon

Pavel Rehak, Brookhaven National Lab.

Outline of this talk:

A) Silicon Drift Detectors

1. principle
2. realization
3. performance

B) Active Pixel Sensors on High Resistivity Silicon

1. Counting versus Integration
2. Principles of Active Pixel Sensors
3. Read–out sequences for the sensor
4. Noise analysis of Sensors

C) Conclusions

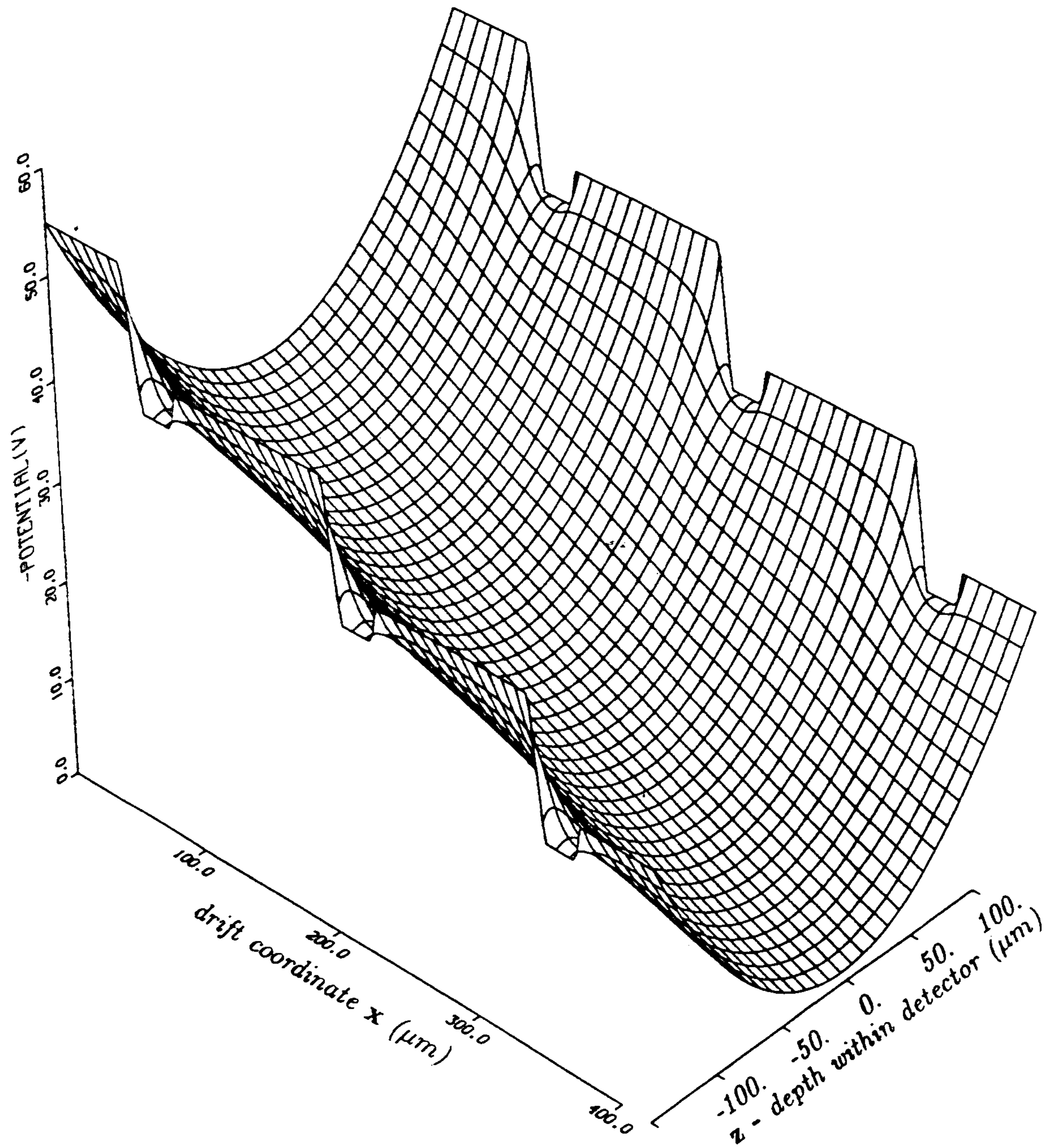


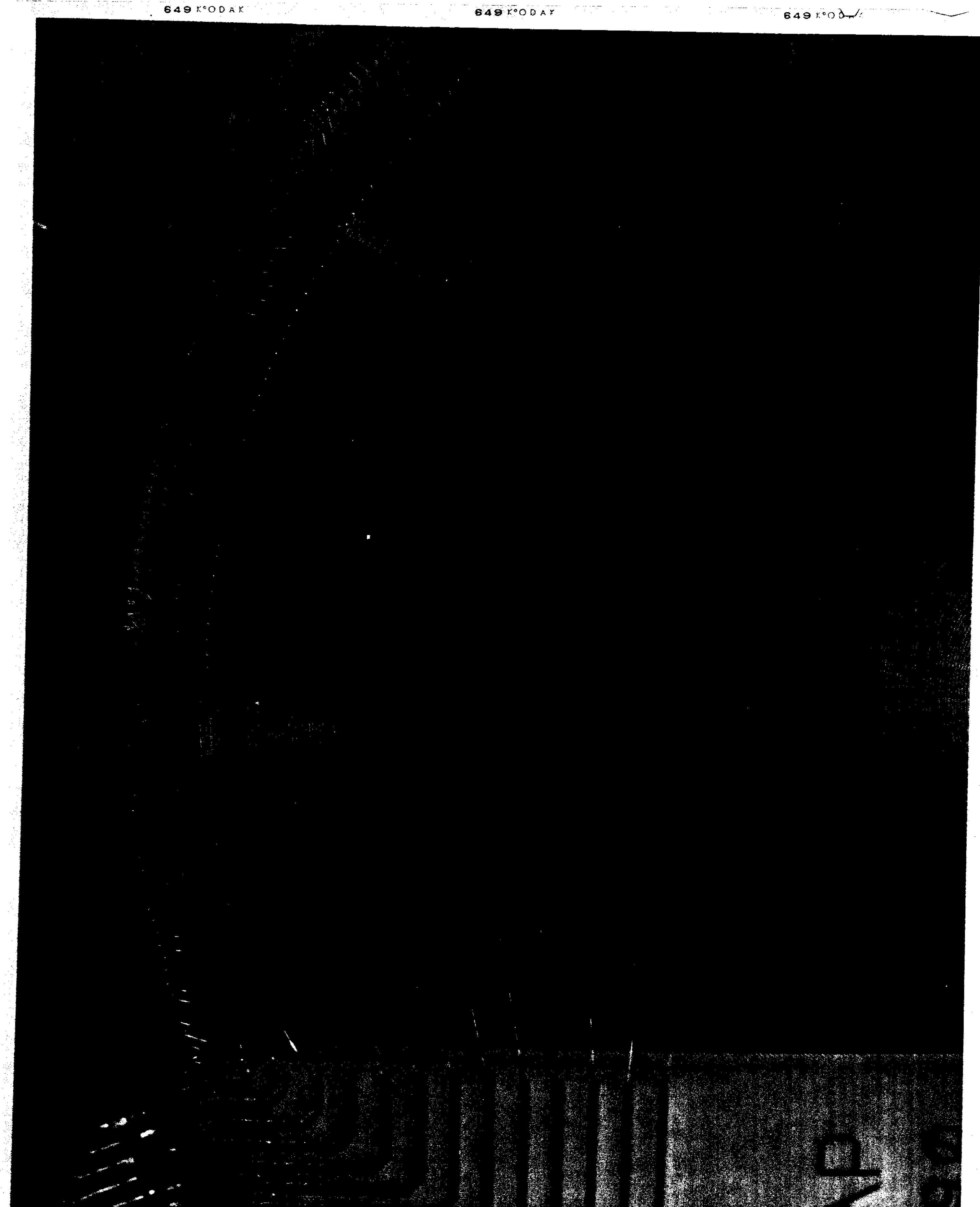
Figure 1: E_{pot}/q or negative potential of electrons in a section perpendicular to the surface of a drift detector along the drift field. Electrons can be visualized as heavy balls moving without the inertia force, downward on the displayed surface.

Optimal noise performance

$$ENC = cnt_1 \times \sqrt[4]{C_{det} \times I_{leak}}$$

$$\tau_{opt} = cnt_2 \times \sqrt[2]{\frac{C_{det}}{I_{leak}}}$$

649 KODAK 649 KODAK 649 KODAK



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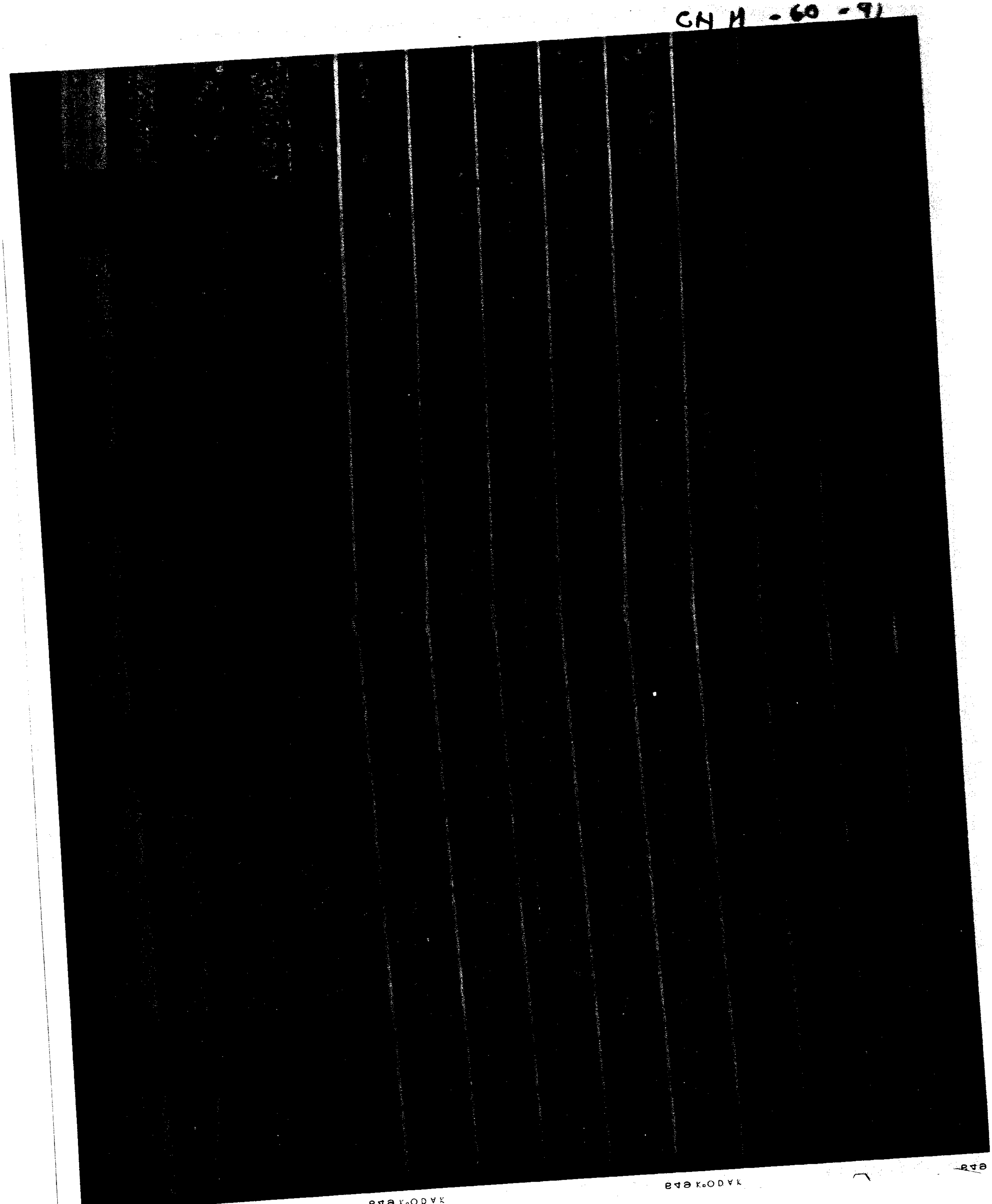
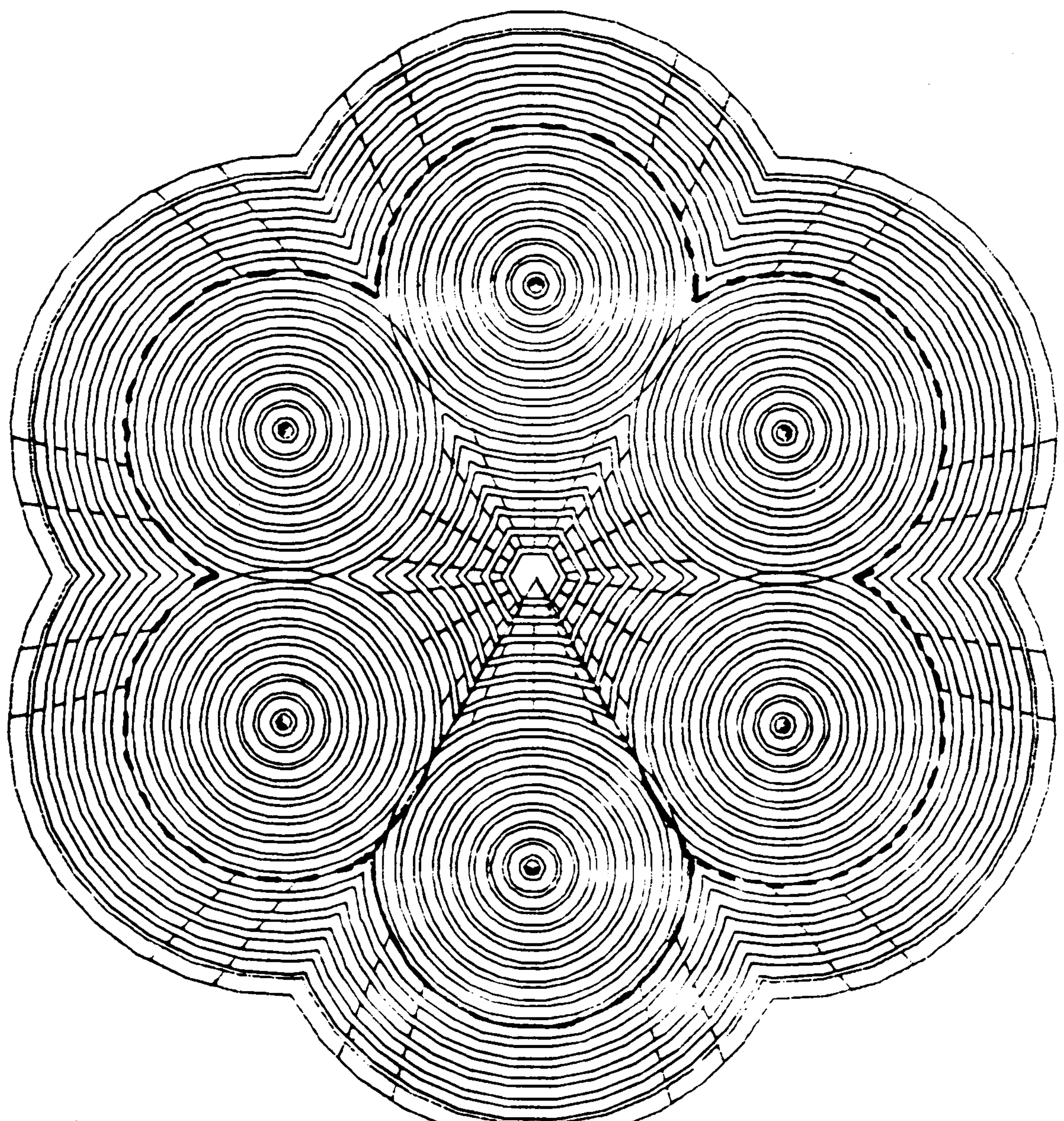


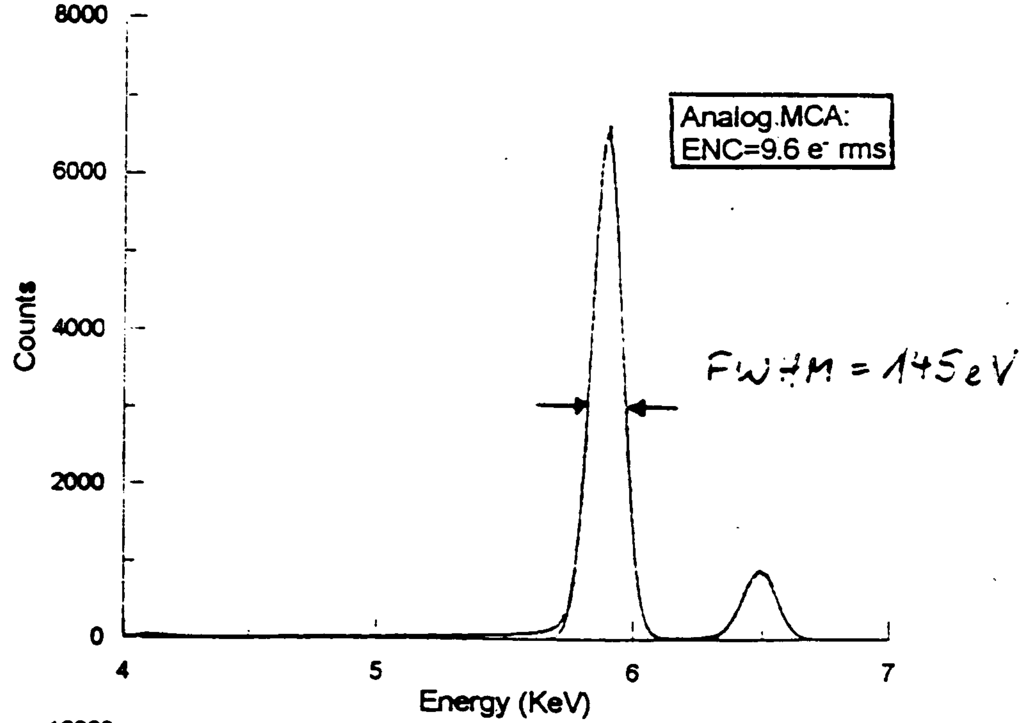
NEW: - On-chip amplification
- integrated voltage devide
- homogeneous, thin entrance window
- sink for surface generated current
- integrated continuous clear

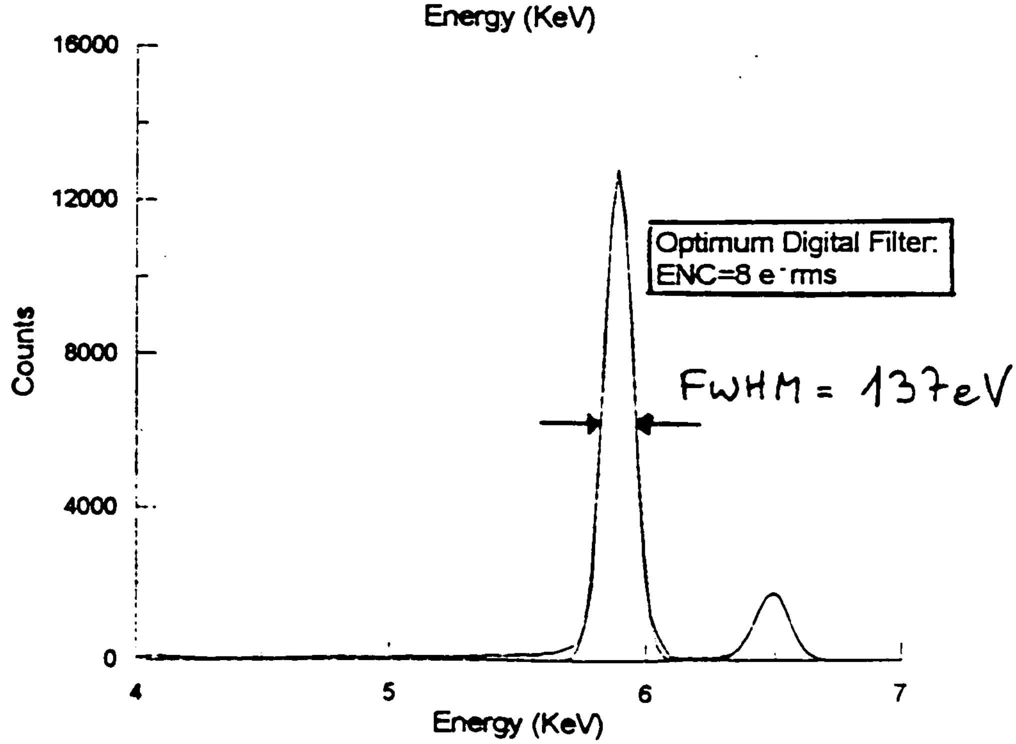


sensitive area of 1 SDC
$A \approx 3.5\,mm^2$

^{55}Fe spectrum

(@ T=220K; τ_{sh}=6μs)

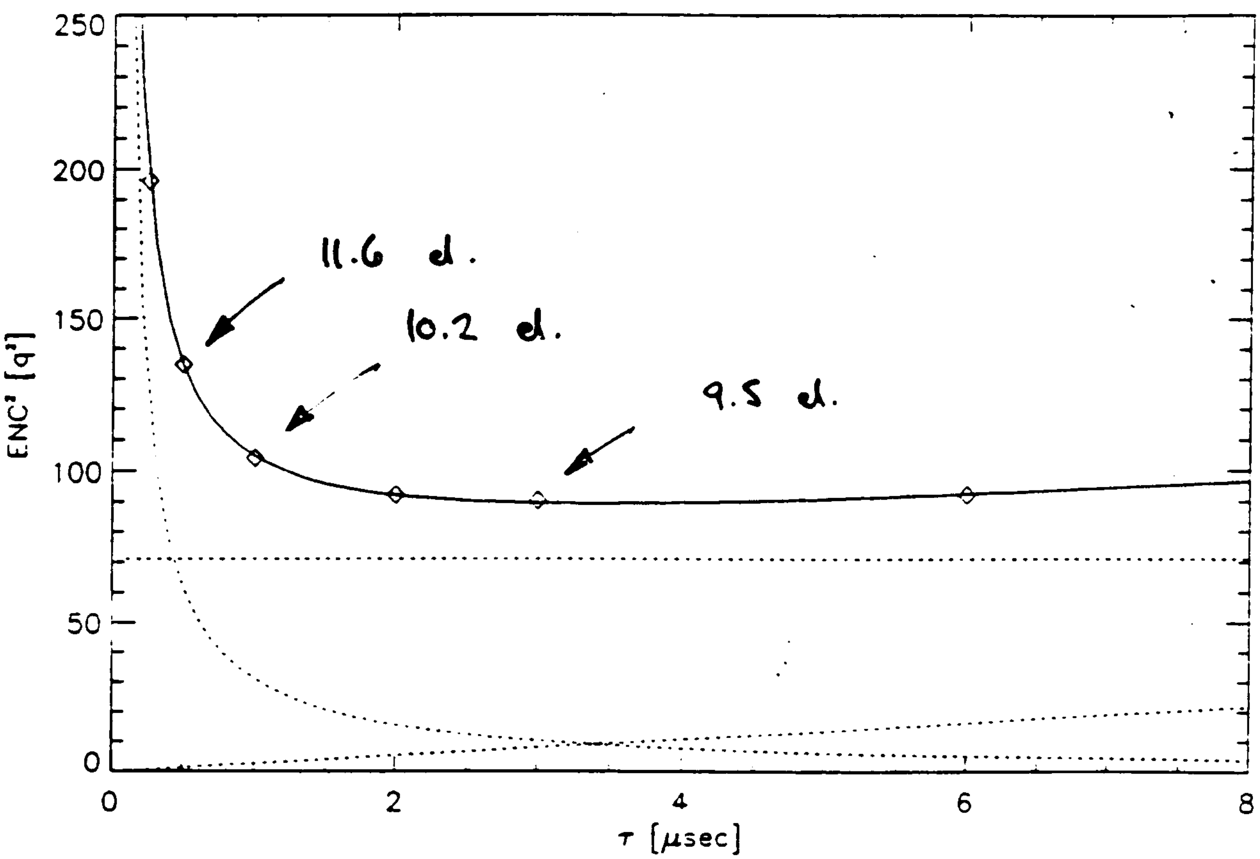




d28 – 3/6b – ma_sac_ff4_c2

sensitive area = 3.5 mm²

temperature = 220 K



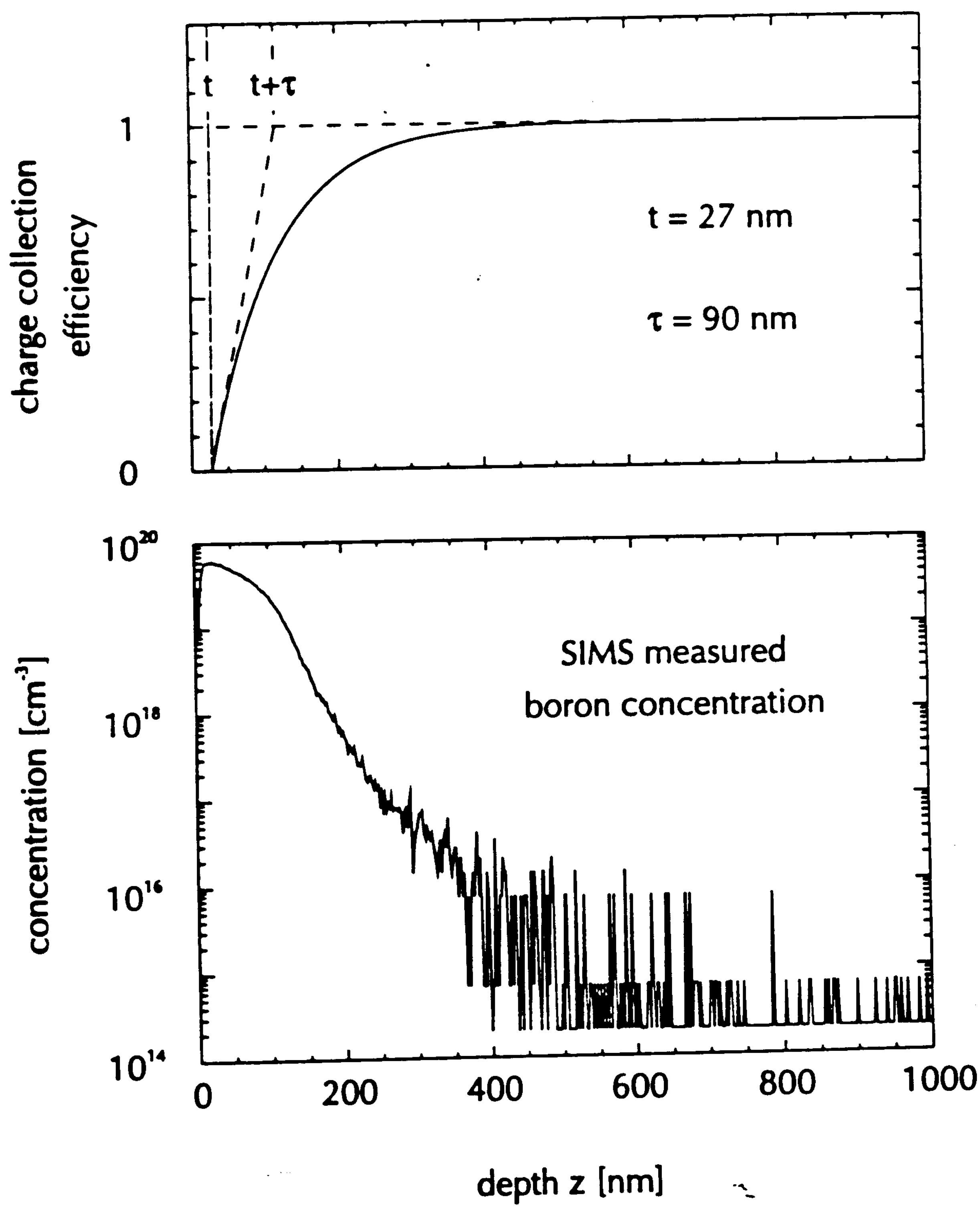
leakage current: I_L = 0.248 pA

1/f coefficient: A_f = 5.525 10^{-12} V^2

total capacitance: C_t = 319.3 fF

MULTI ANODE DEVICE

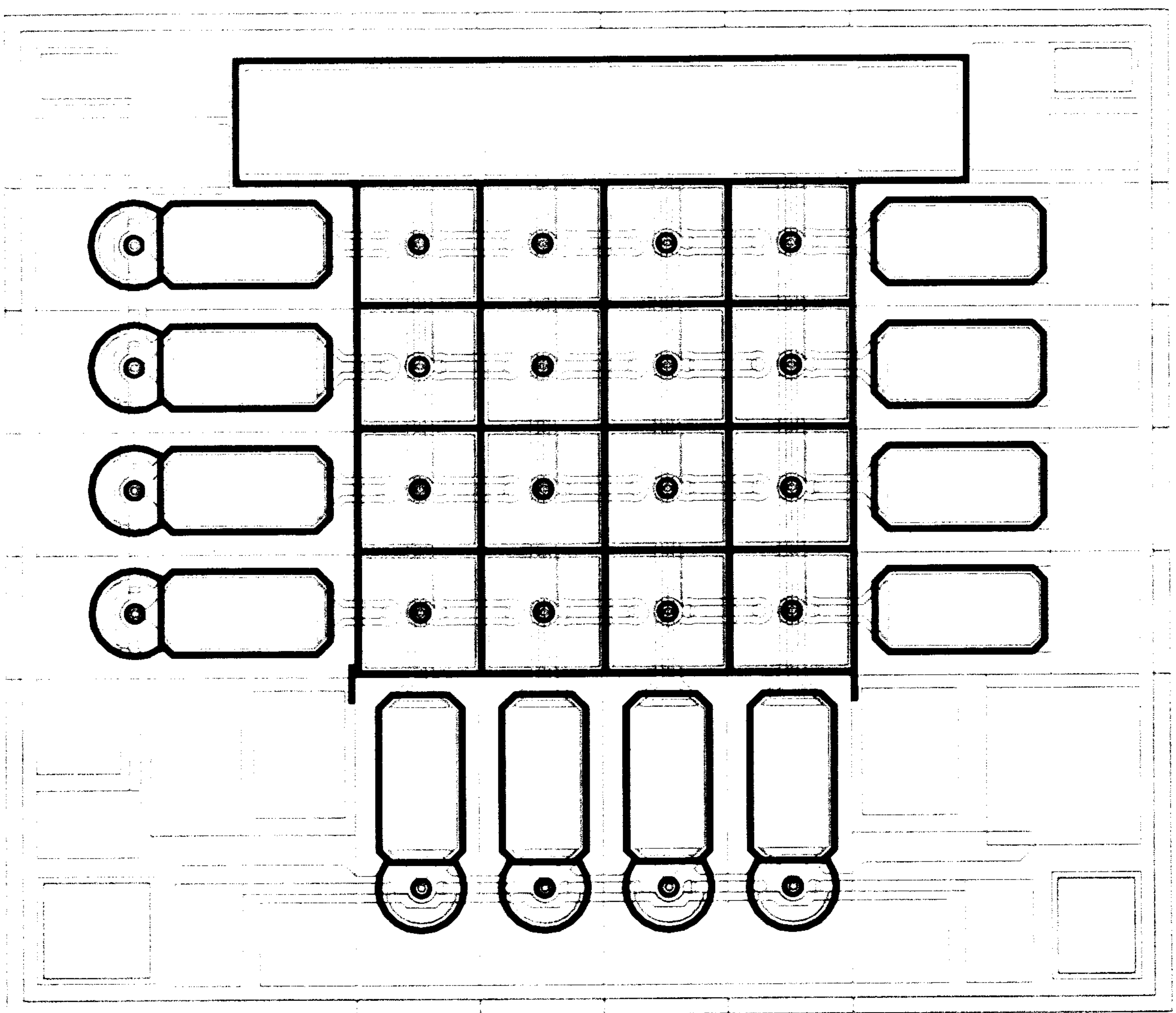
1 CHANNEL


t
t+τ
1
0
charge collection efficiency
t = 27 nm
τ = 90 nm
10^20
10^18
10^16
10^14
concentration [cm^-3]
SIMS measured boron concentration
0
200
400
600
800
1000
depth z [nm]

Properties of a 3mm large SDD:

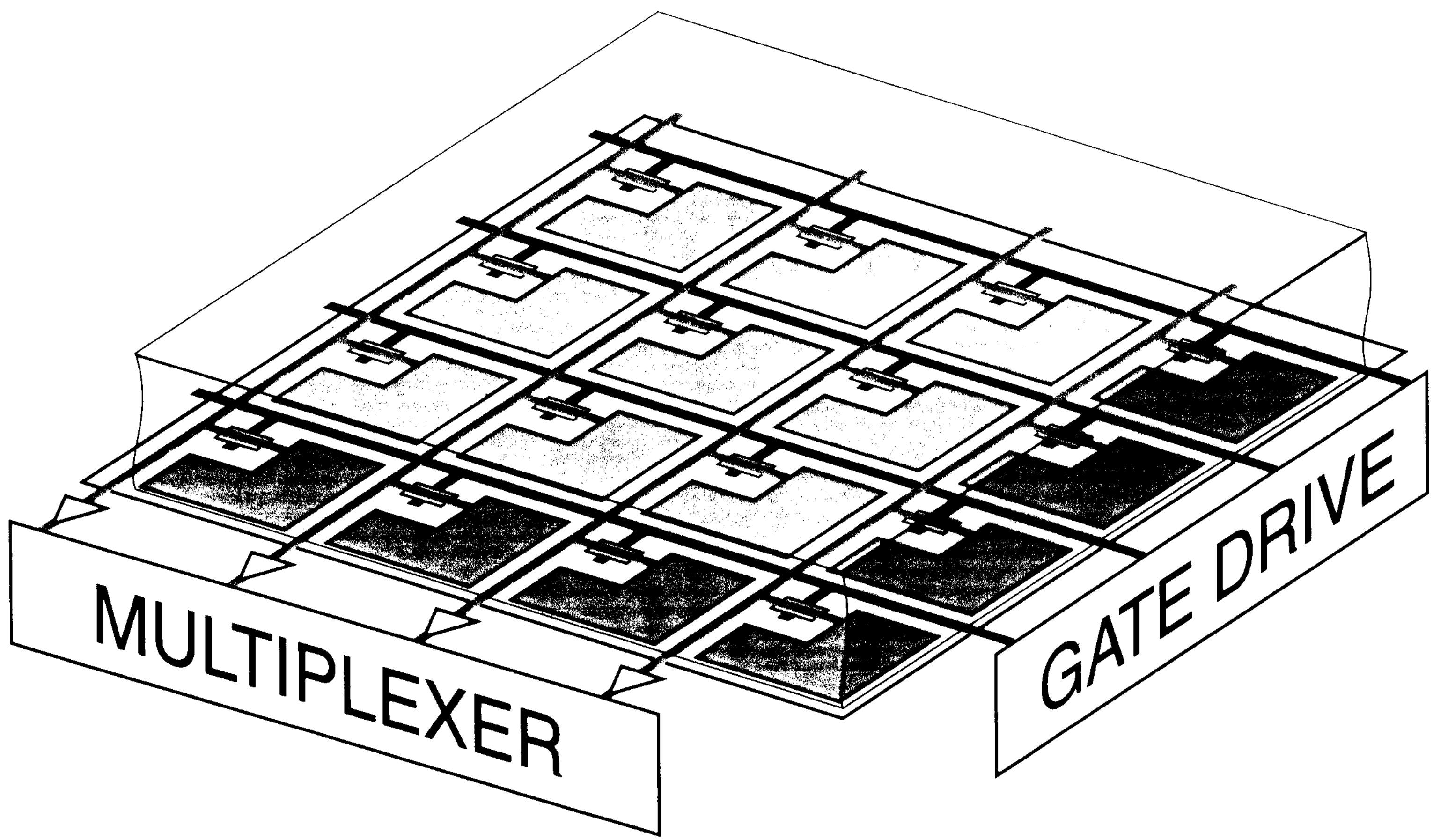
1. electronic noise: ENC = 5–25 electrons
2. entrance dead layer thickness:50–100nm
3. conversion efficiency for 300um silicon: 80% @ 100 eV; 50% @ 200 eV; 80% @ 500 eV; 99% @ 1 keV 99.9% @ 5 keV; 91% @ 10 keV; 52% @ 15 keV;
4. count rate: up to $10^5 Hz$ with up to 1% dead time
5. peak–to–valley ratio 3000:1
6. practically any number of detector possible (1,7,19 etc)
7. power dissipation: 3mW per detector(channel)

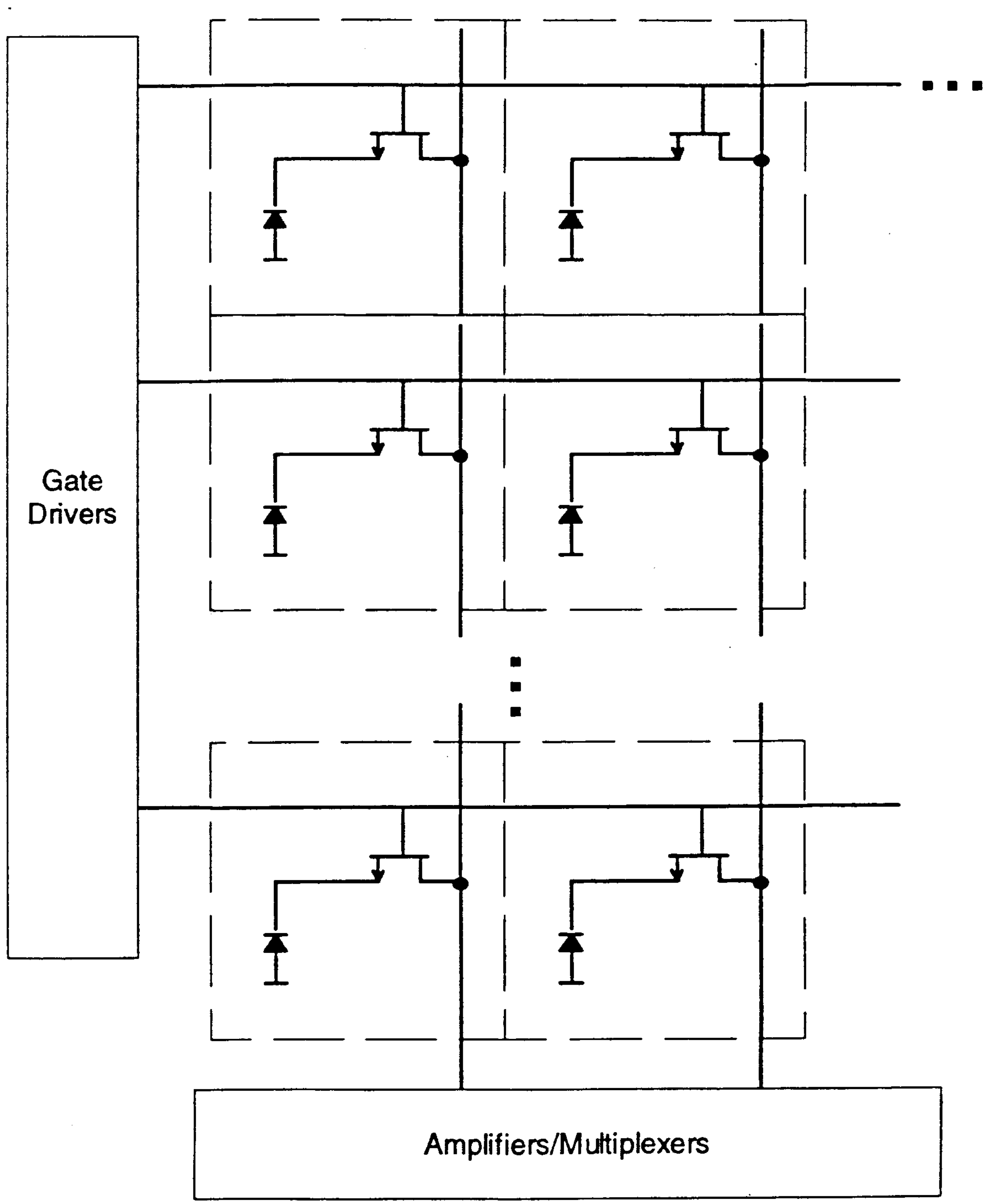
Active Pixel Sensor



The electronic side of a test Active Pixel Sensor having sixteen pixels arranged in 4 lines and 4 columns. Vertical lines connected to the bonding pads at the bottom of the array are the read-out lines. Each line is bonded to a charge sensitive preamplifier. The horizontal lines are terminated with bonding pads on the left hand side as well as on the right hand side of the array. These lines are bonded to the switch controlling electronics.

Active Matrix Readout




Gate
Drivers
Amplifiers/Multiplexers

Counting versus. Integration.

Measured Integrated Charge:

$$Q_{tot} = \sum_{1}^{N} Q_i$$

Summation limit N and Q_i fluctuate. Compound process

$$\overline{Q}_{tot} = \overline{N} \cdot \overline{Q}$$

$$var\left[Q_{tot}\right] = \left(\overline{Q}\right)^2 \cdot var\left[N\right] + \overline{N} \cdot var\left[Q\right]$$

average value of $Q_i = \overline{Q}$ and its r.m.s

$$\overline{Q} = q \cdot E/w$$

$$\sigma_Q = q \cdot \sqrt{F \cdot E/w}$$

$$\overline{N}_Q = \overline{N}; \qquad var\left[N_Q\right] = \overline{N}\left(1 + Fw/E\right)$$

q is an elementary charge, E is the energy of the incident X–ray in eV and $w = 3.6eV$

is the average energy needed to produce one electron–hole pair in silicon, F is the Fano factor, equal to a constant between 0.1 and 0.2 for a good silicon detector

$$(1 + Fw/E) = 1.00006$$

$$\frac{\sqrt{var\left[N_Q\right]}}{\overline{N}_Q} = \frac{\sqrt{\overline{N}\left(1 + 6 \cdot 10^{-5}\right)}}{\overline{N}}$$

$$= \sqrt{\frac{1 + 6 \cdot 10^{-5}}{\overline{N}}} = \sqrt{\frac{1 + 6 \cdot 10^{-5}}{\epsilon \cdot \overline{N}_{incident}}}$$

where $\overline{N} = \epsilon \cdot \overline{N}_{incident}$, where ϵ is the detection efficiency

Conclusion: Practically no loss of performance by integration method

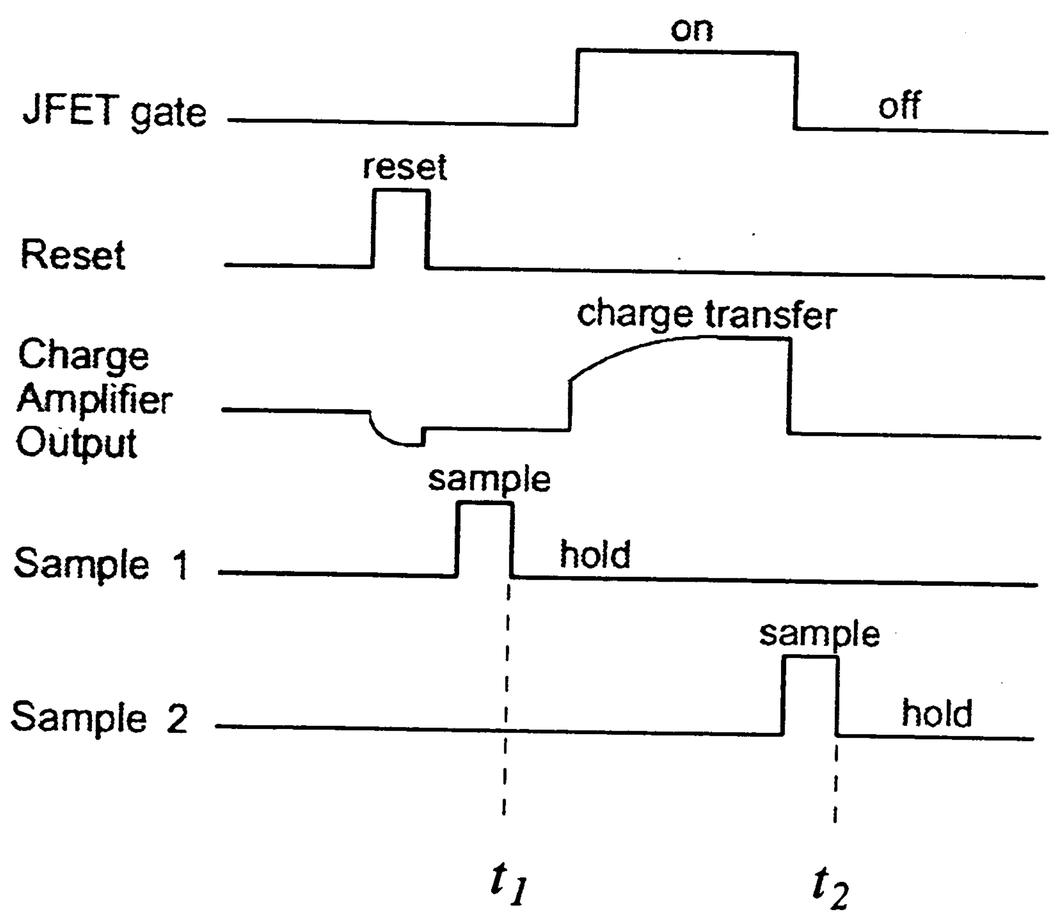


Figure E-4 Timing diagram for column readout

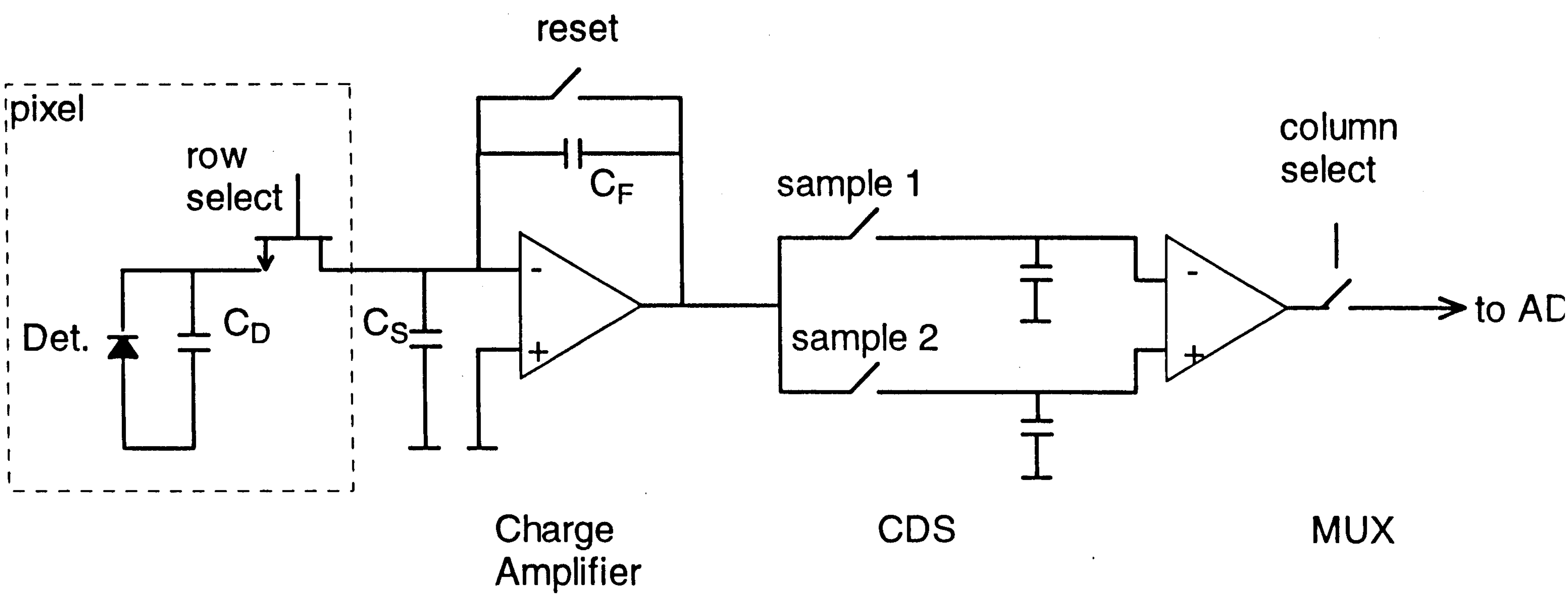


Figure E-3 Column amplifier and multiplexer electronics

Noise Requirements:

About 3300 electron–hole pairs are produced by 1 $12keV$ X–ray. ENC of about 1000 electrons seems to be adequate.

Multiple read–out during on frame.

Exposure time from 10ms to 1s. Read–out of a single line in about 1us. 1000 times 1000 active pixel sensor can be read in 1ms. Operation when we truncate the noise completely for low count pixels. Two different possible read–out sequences:

1. switching (kTC) noise does not accumulate
2. switching (kTC) noise does accumulate

Contributions from individual type of noise:

1. Series noise about 700 electrons
2. Parallel noise about 300 electrons ($I_{leakage} = 10nA/cm^2$)
3. Switching (kTC) noise about 400 electrons.

It seems we can reach the total noise close to 1000 electrons.

CONCLUSIONS:

1. Silicon Drift Detectors are now commercially available detectors with a superior energy resolution and higher rate capabilities than the traditional (classical) silicon lithium drifted detectors.
2. Proposed Active Pixel Sensors on High Resistivity Silicon seems to be almost ideal detectors for the X–ray crystallography at $12keV$.

   a) 1 ms read-out / frame (10^6 pixels)

   b) no dead time while reading

   c) (6 cm × 6 cm) ⟹ (9 cm × 9 cm) active area from a single wafer.